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WATER QUALITY IMPROVEMENT PROGRAM EFFECTIVENESS FOR CARBONATE AQUIFERS IN GRAZED LAND WATERSHEDS[1]

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ABSTRACT: Water quality indicators of two agriculturally impacted karst areas in southeastern West Virginia were studied to determine the water quality effects of grazing agriculture and water quality trends following initiation of water quality improvement programs. Both areas are tributaries of the Greenbrier River and received funding for best management practices under the President's Initiative for Water Quality and then under the Environmental Quality Incentives Program (EQIP). After 11 years of study there was little evidence to suggest that water quality improved in one area. Three and a half years of study in the other area showed little evidence of consistent water quality improvement under EQIP. Lack of consistent water quality improvement at the catchment scale does not imply that the voluntary programs were failures. Increased livestock numbers as a result of successful changes in forage management practices may have overridden water quality improvements achieved through best management practices. Practices that target well defined contributing areas significantly impacting aquifer water quality might be one way to improve water quality at catchment scales in karst basins. For example, a significant decrease in fecal coliform concentrations was observed in subterranean drainage from one targeted sinkhole after dairy cattle were permanently excluded from the sinkhole.

(KEY TERMS: water quality; agriculture; karst hydrology; nonpoint source pollution; environmental impacts; ground water management; EQIP.)

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INTRODUCTION

Nonpoint source pollution has received increasing attention as discrete, or point source, pollutant sources have come under control (USEPA, 2003). Nonpoint source pollution results from a variety of land uses including, but not limited to, agriculture, forestry, mining, construction, urbanization, highways, and recreation. Although each land use will have local importance, agriculture has the widest nonpoint source pollution impact on the nation's water quality and is listed as a source of pollution for 48 percent of impaired river miles in the United States (USEPA, 2002). Some of the contaminants from agricultural areas include nutrients (i.e., nitrate, nitrite, phosphorous, and orthophosphate) from manures and fertilizers, pathogens (i.e., *E. coli, Cryptosporidium, Giardia*, and viruses) from manure, herbicides, insecticides, and sediment.

Coal mined lands were cited as the chief contributor of nonpoint source pollution contaminants in the central Appalachian area. Agriculture was also listed as an important source of contaminants in the eastern part of that region (Paybins *et al.,* 2000). Much of the agricultural land in the Appalachian region lies on limestone and dolomitic carbonate rocks forming karst topography. Eighteen percent of the Appalachian region is karst (Davies, 1984). Pasquarell and Boyer (1995) found that karst land accounts for more than a third of the region's agricultural outputs. Elevated concentrations of nutrients (Boyer and Pasquarell, 1995; Alloush *et al.,* 2003), fecal bacteria (Pasquarell and Boyer, 1995), and *Cryptosporidium parvum* oocysts (Boyer and Kuczynska, 2003) have been found in karst springs of central Appalachia. Boyer and Pasquarell (1995) found a linear relationship between mean annual nitrate concentration and percent of basin in agriculture for central Appalachian karst basins. A direct relationship was also found between percent of basin in agriculture and median

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fecal coliform concentrations in springs (Pasquarell and Boyer, 1995). Quick response of springs to recharge during periods when herbicides were being applied resulted in elevated concentrations of herbicides in ground water (Pasquarell and Boyer, 1996).

Interrupted surface drainage and conduit flow in mature karst terrain result in a rapid and direct connection between surface and ground water (Gerhart, 1986; Hallberg, 1986; Quinlan and Alexander, 1987). Sources of contamination may be detected miles from their origins within very short travel times. Large variations in ground water quality can occur over short periods (Hallberg *et al.,* 1985).

Agricultural watersheds have received a great deal of attention and government funding to reduce impacts of farming on water quality in the past 15 years. Two federal programs in West Virginia included the President's Water Quality Initiative of 1989 authorized by the Food, Agriculture, Conservation, and Trade Act of 1990 (PL 101-624) and EQIP (Government Printing Office, 2003). The Greenbrier Hydrologic Unit Area was one of 74 watersheds picked nationally to receive special funding under the President's Water Quality Initiative for research, voluntary cost sharing, and technology transfer in order to alleviate contamination problems associated with agriculture. Since 1995 the Greenbrier Hydrologic Unit and the Little Levels Area (see description in Study Area section) have received water quality funding under the EQIP program.

The programs' water quality practices concentrated on controlling nutrients and animal wastes. Practices included nutrient management plans, animal watering systems, rotational grazing, crop scouting, manure containment systems, animal exclusions, streambank protection, and sinkhole protection. The purpose of this study was to analyze water quality trends at the watershed scale to determine if the various voluntary cost share practices were affecting water quality improvement at that scale in karst watersheds. The effectiveness of individual practices for improving water quality at local scales was not assessed.

STUDY AREAS AND METHODS

The Greenbrier Hydrologic Unit and the Little Levels Area were the major foci of study. Two karst basins within the Greenbrier Hydrologic Unit were studied (Figure 1). The Hole Basin, 14.5 km^2, 80 percent agricultural, drains to Burn's Cave Spring. Davis Spring Basin, 191.4 km^2, 51 percent agricultural, drains to Davis Spring. Frankford is a small (year 2000 population less than 1,000) rural community in the Hole Basin. Changes in land use percentages were not significant during the study period. Lewisburg is a small (year 2000 population 3,624) city in the Davis Spring Basin. The Greenbrier Hydrologic Unit is underlain by Mississippian carbonate bedrock of the Greenbrier Formation. Nearly all of the recharge to the karst aquifer in both basins is autogenic. However, there is some allogenic recharge by small streams flowing off the older Maccrady shale on the eastern border of the limestone and off of the younger Mauch Chunk Group noncarbonate sedimentary rocks (primarily sandstones and shales) on the western side. A sinkhole plain dominates the study area and includes thousands of karst features such as sinkholes and blind valleys that funnel surface water into the karst aquifer. The area lies within a synclinal basin of very moderate dip. The caves are generally developed along the strike with interconnecting passages developed on the dip. Water flows down dip (northwest) and then along the strike (northeast in the Hole Basin and southwest in Davis Spring Basin) to the resurgence springs (Jones, 1973). There is virtually no surface drainage system developed on the limestone of either basin except for a few small surface streams that totally sink into the limestone on the western side of Davis Spring Basin. Water sampling started at Davis Spring and Burn's Cave Spring in June 1990 and is ongoing. Sampling intervals have varied over time. Monthly water sampling at several sites within the Hole cave system, which drains to Burn's Cave Spring, started in 1991 and is ongoing. The subsurface sampling scheme is described and illustrated by Boyer and Pasquarell (1996, 1999).

The Little Levels Area is bounded by mountainous terrain with pristine national forest lands to the west and the Greenbrier River to the east (Figure 2). The mountains are primarily made up of noncarbonate sedimentary rocks (largely sandstones and shales) of the Mauch Chunk and Pottsville Groups. The agricultural lands between the mountains and the river are drained by a karst aquifer composed of Mississippian-age limestone of the Greenbrier formation. The Little Levels Area contains the small (year 2000 population 243) rural community of Hillsboro. Monthly water sampling started in October 1996 and ended in June 2000. Much of the karst aquifer recharge is allogenic runoff from the forest noncarbonate areas to the west. Agricultural drainage enters the carbonate aquifer through autogenic recharge. Hills Creek and Bruffey Creek flow across noncarbonate sedimentary rocks and sink together in a large swallow hole at the contact with the carbonate bedrock. Hills Creek and Bruffey Creek eventually resurface at Locust Spring and flow as Locust Creek to the Greenbrier River. Millstone Creek flows off Viney Mountain and sinks into the carbonate rocks, where it joins water from Hills Creek and Bruffey Creek and reappears at

Locust Spring. Stamping Creek flows off the noncarbonate bedrocks, begins to sink in its bed at about 745 m elevation, flows underground through the Patton Limestone of the Greenbrier Group, resurfaces near Blue Spring at about 700 m elevation, and continues flowing as a surface stream to the Greenbrier River (Storrick, 1992). Autogenic recharge waters from the farmlands north of Hillsboro reappear at Blue Spring. Autogenic recharge waters from the farmlands south of Hillsboro resurface at Mill Run Spring and flow a short distance as a surface stream (Mill Run) to the Greenbrier River. A more complete description of the Little Levels Area hydrology is found in White and Schmidt (1966).

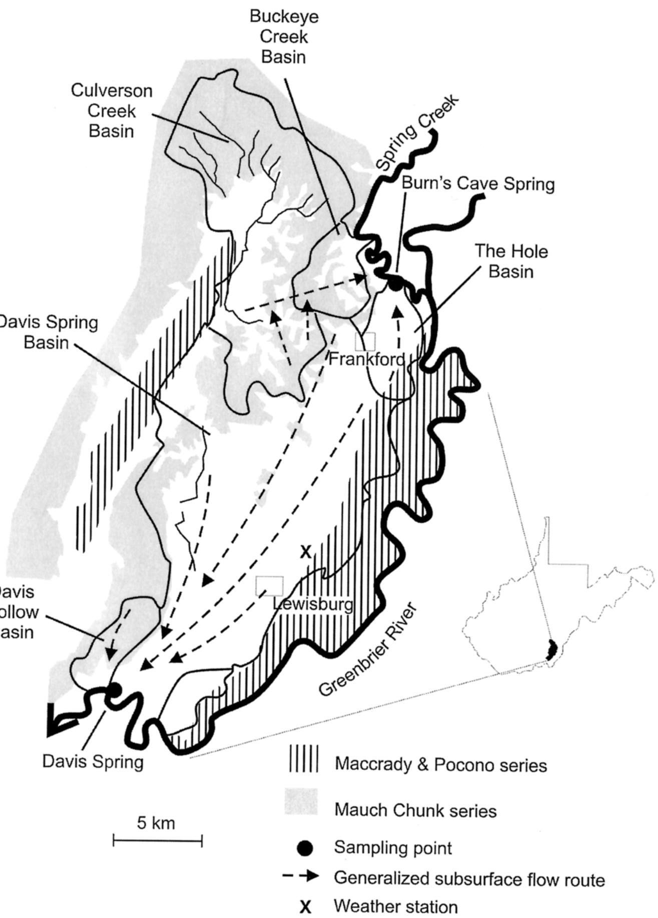

Figure 1. Greenbrier Hydrologic Unit Area in West Virginia. Greenbrier Limestone is the nonshaded area.

Annual precipitation data from weather stations at Lewisburg Airport and Buckeye are summarized in Table 1. The Lewisburg Airport station is located within the Davis Spring Basin, and the Buckeye station is located about 8.5 km northeast of Hillsboro or the center of the Little Levels Area. Annual precipitation in the Greenbrier Hydrologic Unit fell within 10 percent of normal (1,031 mm) at Lewisburg Airport nine out of 14 years. Annual precipitation was less than 90 percent of normal in 1992, 1999, and 2001 and more than 10 percent above normal in 1996 and 2003. Buckeye annual precipitation was within 10 percent of normal (1,139 mm) two out of five years. Annual precipitation in 1998 and 1999 was less than 90 percent of normal, and 1996 annual precipitation was more than 10 percent above normal.

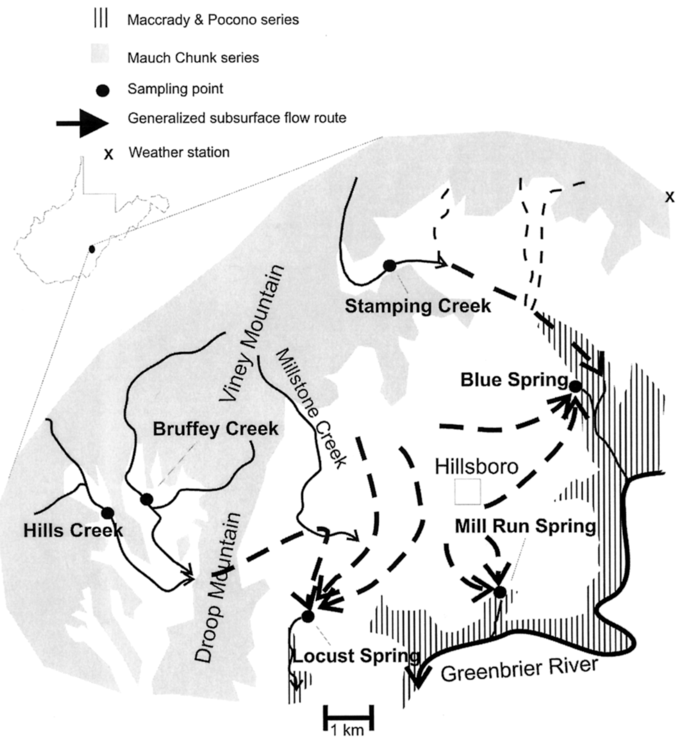

Figure 2. Little Levels Area in West Virginia. Greenbrier Limestone is the nonshaded area.

Water samples were collected in sterile, acid washed plastic bottles that were rinsed with sample water at least once before taking the actual samples. Sample bottles were placed on ice for transport back to the laboratory, where fecal coliform analyses were started within six hours of sample collection. About 30 ml of sample was filtered (0.45 µm) and stored at less than 4˚C until analyses for nitrate-nitrogen (N) and other ions could be performed. Nitrate-N concentration was determined by suppressed ion chromatography. Fecal coliform concentrations were determined by membrane filtration (0.45 µm) onto mFC medium (Eaton *et al.,* 1995).

Basic statistical analyses were performed with the Statistical Analysis System (SAS™) (SAS Institute, Inc., 2001) unless stated otherwise. Most of the raw and log transformed fecal coliform data and some of

TABLE 1. Observed and Normal Annual Precipitation at Lewisburg and Buckeye, West Virginia.

	Lewisburg		Buckeye	
Year	**Annual Precipitation (mm)**	**Long Term Normal Precipitation (mm)**	**Annual Precipitation (mm)**	**Long Term Normal Precipitation (mm)**
1990	1,055	1,031		
1991	955	1,031		
1992	885	1,031		
1993	1,078	1,031		
1994	995	1,031		
1995	1,126	1,031		
1996	1,451	1,031	1,400	1,139
1997	940	1,031	1,037	1,139
1998	998	1,031	1,013	1,139
1999	875	1,031	948	1,139
2000	948	1,031	1,093	1,139
2001	863	1,031		
2002	1,078	1,031		
2003	1,267	1,031		

the nitrate-N data failed standard tests of normality (Shapiro and Wilk, 1965), so nonparametric tests were used to test for temporal trends. The statistical software WQSTAT (Loftis *et al.,* 1989) was used to perform the nonparametric Seasonal Kendall tests (Hirsch *et al.,* 1982; Kendall and Gibbons, 1990) of increasing or decreasing temporal trends in nitrate-N or fecal coliform concentrations. Statistical significance was set at $P \leq 0.05$.

The high degree of variability exhibited by the data (Figures 3 through 5) makes trend visualization difficult. An advantage of the Seasonal Kendall test is that it is a robust, nonparametric test based on ranks, thus removing much of the variation. The test is robust against nonnormality and censoring (Hirsch *et al.,* 1982). The test is rendered insensitive to seasonality by computing the Mann Kendall test on each of the seasons (months) separately. Kendall's test statistics for each of the seasons are then summed to produce an overall test statistic (Helsel and Hirsch, 2002).

RESULTS

Simple statistics of nitrate-N and fecal coliform concentrations at each of the study sites are shown in Tables 2 and 3. In the Greenbrier Hydrologic Unit, both nitrate-N and fecal coliform concentrations at Burn's Cave Spring exceeded those at Davis Spring. The basin drained by Burn's Cave Spring contains a 30 percent greater proportion of area in agriculture than the basin drained by Davis Spring. In the Little Levels Area, nitrate-N and fecal coliform concentrations at the springs exceeded those at the insurgence streams, which flow from the forested mountains. Significant contributions of contaminants from the agricultural lands overlying the karst system probably caused the increased levels at the springs. Wildlife may have contributed contaminants, but Boyer and Pasquarell (1995, 1996, 1999) and Pasquarell and Boyer (1995) showed a direct relationship between livestock activity and nitrate-N and fecal coliform concentrations in the karst subterranean streams and springs.

Table 4 shows the Seasonal Kendall tau test results by study sites. In the Greenbrier Hydrologic Unit there was a significant temporal decrease in nitrate-N concentrations at Davis Spring and a significant temporal increase in fecal coliform concentrations at Burn's Cave Spring. In the Little Levels Area there were no significant temporal trends in fecal coliform concentrations except at Blue Spring, which showed a decreasing trend. Nitrate-N concentrations showed a decreasing trend at Locust Spring, as did both insurgence streams, Hills Creek and Bruffey Creek. Blue Spring and Mill Run Spring, which are recharged primarily by water percolating from agricultural lands, showed no decreasing temporal trends in nitrate-N concentrations.

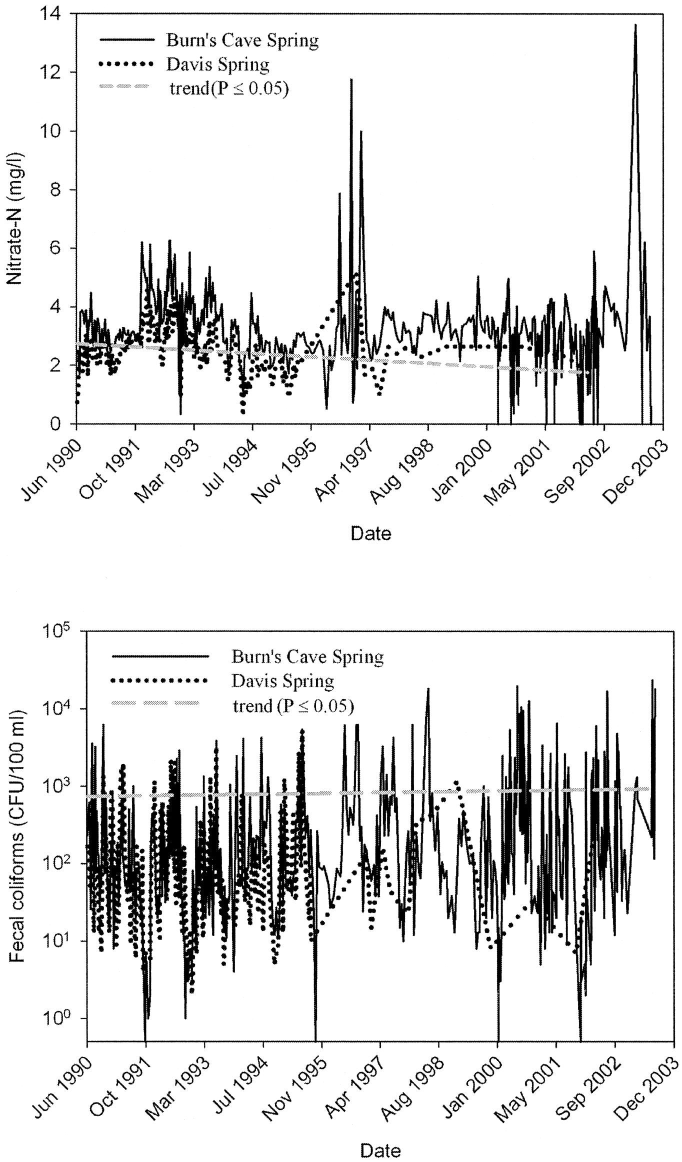

Figure 3. Observed Nitrate-N Concentrations and Fecal Coliform Concentrations at Burn's Cave Spring Draining the Hole Basin and Davis Spring Draining Davis Spring Basin in the Greenbrier Hydrologic Unit Area in West Virginia.

Figures 3, 4, and 5 show all the nitrate-N and fecal coliform concentrations at most of the study sites. Significant trends ($P \leq 0.05$) are denoted in Figures 3, 4, and 5 by gray dashed lines. The trend lines in Figure 3 show that nitrate-N concentration at Davis Spring decreased from about 2.7 mg/l to 1.8 mg/l, and fecal coliform concentration at Burn's Cave increased from about 740 Colony Forming Unit per 100 milliliters (CFU/100 ml) to 920 CFU/100 ml. The most significant trends were seen in nitrate concentrations (Figure 4) at Hills Creek (0.9 mg/l to 0.4 mg/l) and Locust Spring (1.5 mg/l to 0.9 mg/l). Fecal coliform concentrations at Blue Spring decreased from 220 CFU/100 ml to 160 CFU/100 ml (Figure 5).

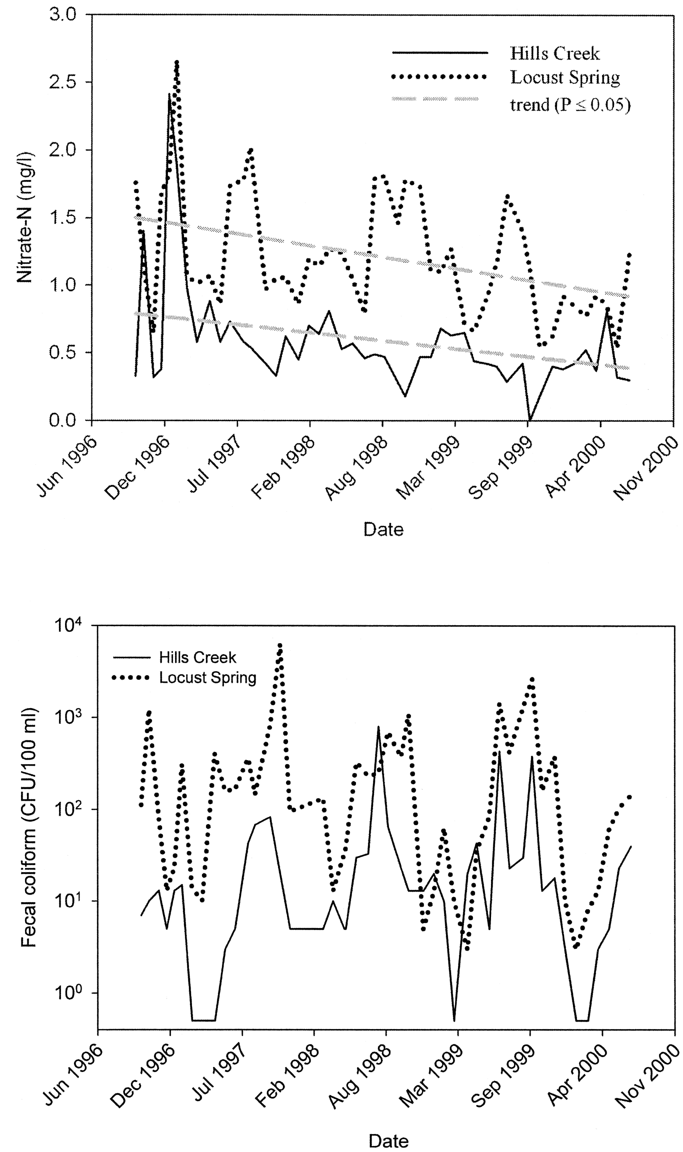

Figure 4. Observed Nitrate-N Concentrations and Fecal Coliform Concentrations at Hills Creek and Locust Spring in the Little Levels Area in West Virginia.

DISCUSSION

Nitrate-N concentrations decreased in two out of three insurgence streams in Little Levels Area, but a similar change was not reflected at two out of three of the springs. The significant reduction of nitrate-N concentrations at Locust Spring was most likely a result of highly significant decreasing trends in nitrate-N concentrations in its two insurgence streams, Hills Creek and Bruffey Creek, rather than on-farm practices (see Table 4). Accumulation and storage of N in soils and the epikarst (Boyer and Alloush, 2001; White, 2004) might require years of leaching before decreasing concentrations are seen in ground water. It is unclear why there was a decreasing trend in nitrate-N concentrations in the insurgence streams as both flow from forest land where no known best management practices were applied. Timing of precipitation might have affected nitrate-N concentrations; however, a Kendall seasonal test for precipitation trends, using monthly total precipitation amounts, failed to show any increasing or decreasing trends in precipitation. Monthly total precipitation amounts were also transformed to monthly surpluses or deficits relative to the average monthly precipitation for the previous three months. Kendall's seasonal test for trend of the transformed precipitation failed to show any increasing or decreasing trends. A detailed water balance analysis might reveal periods that were favorable or not to nitrate movement and explain the trends found in this study. The forest lands were not surveyed to determine if any silvicultural activities occurred in the watersheds prior to or during the study period.

Whereas the primary agricultural enterprises in the Little Levels Area were based on grazing beef cattle and sheep, most of the best management practices installed during the study period dealt with control of animal manure by restricting access to sensitive sites. It is reasonable to expect that changes in nitrate-N concentrations at the springs would be accompanied by similar (increasing or decreasing) changes in fecal coliform concentrations. A significant reduction in fecal coliform concentrations was observed at one of the three Little Levels Area springs. No changes in fecal coliform concentrations were observed at Locust Spring or Mill Run Spring. There was a highly significant decreasing trend in fecal coliform concentrations at Blue Spring but no associated change in nitrate-N concentrations. During the course of the study new fencing patterns installed by the landowner around Blue Spring decreased the frequency of animal visitations around the spring. The other springs sampled in this study were not fenced. The decreasing trend in fecal coliform concentrations was probably a result of that fencing rather than any broad scale practices on the recharge area. Even though fecal coliform concentrations at Blue Spring decreased, the concentrations were still greater than 150 CFU/100 ml at the end of the study. The importance of the finding that fencing livestock out of the immediate area of the spring decreased fecal coliform concentrations cannot be overstated. Further improvements in the microbiological integrity of the spring water might be realized by excluding livestock from critical sinkholes in the recharge area.

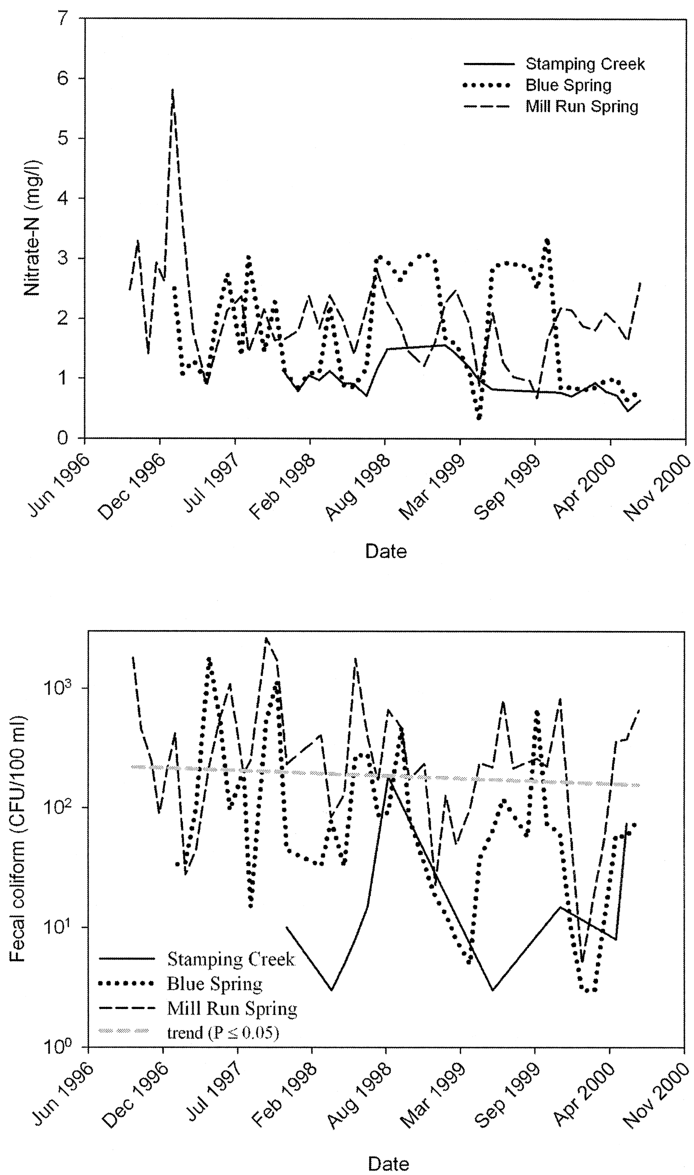

Figure 5. Observed Nitrate-N Concentrations and Fecal Coliform Concentrations at Stamping Creek, Blue Spring, and Mill Run Spring in the Little Levels Area in West Virginia.

Concerning the Greenbrier Hydrologic Unit, the decreasing trend in nitrate-N concentrations at Davis Spring was not accompanied by any change in fecal coliform concentrations. As in the Little Levels Area, animal grazing is the predominant land use within the basin, and most practices dealing with animals and manure would be expected to impact both water quality parameters. It is possible that the basin realized a reduction in fecal coliform bacteria from

TABLE 2. Simple Statistics of Nitrate-N Concentrations at Each of the Study Sites.

Study Site	Period of Record	Number of Samples	Mean (mg/L)	Range (mg/L)
Greenbrier Hydrologic Unit				
Davis Spring	June 1990 to May 2002	220	2.54	0.28 to 5.20
Burn's Cave Spring	June 1990 to October 2003	503	3.23	< 0.01 to 13.62
Little Levels Area				
Hills Creek	October 1996 to June 2000	47	0.58	< 0.01 to 2.41
Bruffey Creek	October 1996 to June 2000	47	0.63	< 0.01 to 2.20
Locust Spring	October 1996 to June 2000	47	1.21	0.54 to 2.66
Stamping Creek	November 1997 to June 2000	22	0.96	0.47 to 1.56
Blue Spring	February 1997 to June 2000	41	1.75	0.30 to 3.36
Mill Run Spring	October 1996 to June 2000	47	2.01	0.68 to 5.81

TABLE 3. Simple Statistics of Fecal Coliform Bacteria Concentrations at Each of the Study Sites.

Study Site	Period of Record	Number of Samples	Median (CFU/100 ml)	Range (CFU/100 ml)
Greenbrier Hydrologic Unit				
Davis Spring	June 1990 to May 2002	214	53	< 1 to 5,200
Burn's Cave Spring	June 1990 to September 2003	494	116	< 1 to 23,200
Little Levels Area				
Hills Creek	October 1996 to June 2000	45	13	< 1 to 800
Bruffey Creek	October 1996 to June 2000	45	23	< 1 to 370
Locust Spring	October 1996 to June 2000	45	132	3 to 6,240
Stamping Creek	November 1997 to June 2000	20	2	< 1 to 183
Blue Spring	February 1997 to June 2000	39	63	< 1 to 1,800
Mill Run Spring	October 1996 to June 2000	45	234	5 to 262

agriculture but was offset by contributions from other land uses in the basin. The basin does have more urban and suburban area than other karst basins in the region. The higher percentage of impervious surfaces such as roads and parking lots and of residential lawns might be funneling storm runoff into the aquifer. Rapid storm runoff characteristic of urbanizing areas reduces the opportunity for infiltration through the soil, where nitrification can occur resulting in lower nitrate concentrations (Jordan *et al.,* 1997; Im *et al.,* 2003).

The decrease in nitrate-N concentrations observed at Davis Spring was not similarly observed at Burn's Cave Spring. Burn's Cave Spring drains the Hole Basin, which has the most intense agricultural use in the Greenbrier Hydrologic Unit. Eighty percent of its area is agricultural. Just as with the other study sites, the primary agricultural activity is livestock grazing. The basin also contains three dairies that do not meet the criteria to be classified as confined animal feeding operations. Storm based sampling at Burn's Cave Spring indicates that nitrate-N concentrations are reduced during peak stormflows (unpublished data), but fecal coliform bacteria concentrations are greatest at storm peaks (Boyer and Kuczynska, 2003). In addition there was a highly significant trend of increasing fecal coliform concentrations at Burn's Cave Spring.

The increase in fecal coliform concentrations is perplexing. The dairies would be suspect for their contributions of fecal coliforms as a result of concentrating animals in the barnyard areas. However, there was a decrease in the number of dairy cattle during the study period. One dairy is located near the boundary of the basin and drains its milk house waste and farmyard drainage to a detention basin located outside the basin and off of karst land. The dairy closest to the spring installed a manure detention structure under the President's Initiative program. Manure from that dairy is then spread according to recommendations in a farm management plan. The third dairy was a major contributor of fecal coliforms to the karst aquifer (Boyer and Pasquarell, 1999). However, that dairy ceased dairy operations in 1999 and converted entirely to pasture grazed beef cattle. As a result, manure and dairy wastes were no longer being introduced into the problem sinkhole that is drained by the subterranean stream, Bloodstone Stream, described by Boyer and Pasquarell (1999). The number of beef cattle in the basin increased during the study period and might have caused the increased fecal coliform concentrations at the spring.

TABLE 4. Seasonal Kendall τs Used to Test for Temporal Long Term Mean Upward or Downward Trends in Nitrate-N and Fecal Coliform Concentrations.

Study Site	Nitrate-N (τ)	Fecal Coliform (τ)
Greenbrier Hydrologic Unit		
Davis Spring	-2.38*	0.67
Burn's Cave Spring	-1.02	3.29*
Little Levels Area		
Hills Creek	-4.77*	1.02
Bruffey Creek	-4.98*	-0.23
Locust Spring	-2.17*	-0.66
Stamping Creek	-1.62	0.00
Blue Spring	-1.07	-3.01*
Mill Run Spring	-1.14	-0.76

Notes: Downward trends are indicated by a negative τ and upward trends are indicated by a positive τ. An asterisk after the τ indicates statistical significance ($P \leq 0.05$).

The Hole Basin is underlain by a substantial 37 km cave system known as The Hole. Monthly water sampling in several cave streams in a small portion of The Hole started in 1991 and is ongoing. The sampling scheme and spatial and temporal differences in nitrate-N and fecal coliform concentration in the cave streams are discussed by Boyer and Pasquarell (1996, 1999). Five first-order cave streams (Upper Adjacent Stream, Bullwinkle Stream, Spike Stream, FE Survey Stream, and Upper Maze Stream) drain pasture grazed by beef cattle, and one first-order cave stream, Bloodstone Stream, drains the dairy's farmyard and milk house area. Seasonal Kendall trend tests were run for nitrate-N and fecal coliforms in each of the six cave streams. Nitrate-N concentrations increased (Bullwinkle Stream and Spike Stream) in two of the five pasture impacted cave streams and did not change at Bloodstone Stream. Fecal coliform concentrations increased in three out of five of the pasture impacted cave streams and decreased in Bloodstone Stream. A Kendall seasonal test for precipitation trends failed to show any increasing or decreasing trends in precipitation that might have been correlated with nitrate-N or fecal coliform concentrations.

Although the dairy impacting Bloodstone Stream ceased dairy operations in 1999, no decreasing trend in nitrate-N concentrations was observed, but fecal coliform concentrations decreased from a mean of 20,691 CFU/100 ml at the beginning of the study to a mean of 83 CFU/100 ml at the end of the study. Nitrate-N concentrations might still be high because of stored N in the soil and the epikarst. Eventually those pools of N are expected to decrease because fecal material and milk house wastes are no longer entering the sinkhole. Fecal coliforms are living organisms, and die-off probably accounts for much of the concentration decrease in Bloodstone Stream.

Boyer and Pasquarell (1999) considered Bloodstone Stream to be a major contributor of fecal coliforms appearing at Burn's Cave Spring. However, a significant increasing fecal coliform bacteria trend was observed at Burn's Cave Spring in spite of a significant decrease in Bloodstone Stream. The increasing trends in fecal coliform bacteria concentrations in the pasture impacted cave streams might be negating the decreasing contributions from Bloodstone Stream.

A grassland demonstration farm in the Hole Basin has been successful with improving forage quality and production without increased additions of inorganic nutrients. Animal carrying capacity increased on the demonstration farm, resulting in some neighboring farmers adopting some of the management practices on their own farms. Cattle and calf inventories in Greenbrier County increased from 34,000 in 1992 to 39,500 in 1997 (USDA, 1999). Livestock populations are only available for the county, but as nearly all of the grazing occurs on the limestone areas it is assumed that the increases in livestock numbers also occurred on the limestone areas. The 15 percent increase in livestock numbers in the county was similar to the 13.5 percent increase in stocking rate (3.1 head/ha to 3.5 head/ha) on the demonstration farm. Increasing herd sizes are accompanied by increased fecal production, which might be a contributing factor to increasing fecal coliform concentrations in pasture impacted cave streams and at Burn's Cave Spring.

The sampling period in the Little Levels Area (October 1996 through June 2000) was considerably shorter than the sampling period in the Greenbrier Hydrologic Unit (June 1990 through September 2003), making comparison between the two areas tenuous. Analysis of a subset of the Burn's Cave Spring data that covers the same period of record as that in the Little Levels Area fails to show any increasing or decreasing trends in nitrate-N or fecal coliform concentrations. The Davis Spring site was not sampled as frequently as Burn's Cave Spring during the shortened record, so a subset of the data was not analyzed.

CONCLUSIONS

There was little evidence that water quality improvement programs were having a consistent, significant effect on nitrate-N concentrations or fecal coliform concentrations at the watershed scale in the karst basins studied. Although there were a few indicators of some improvement in water quality, there was also one indicator of degraded water quality (fecal coliform concentrations at Burn's Cave Spring) and several instances of no significant trends. Successful adoption of management practices that lead to improvements in forage quality and production are leading to higher livestock populations that might subsequently be contributing more fecal bacteria and nutrients to the karst aquifers.

Decreasing trends in nitrate-N at Locust Spring in the Little Levels Area appeared to be related to significant decreasing trends in the two main insurgence streams, Hills Creek and Bruffey Creek. Autogenic recharge water from farmland overlying the karst aquifer probably had little effect on the decreasing trend because an accompanying decrease in fecal coliform concentrations was not observed. A decreasing trend in fecal coliforms at Blue Spring might have been a result of a new fencing pattern at the spring rather than on-farm practices in the recharge area.

An increasing trend in fecal coliform concentrations at Burn's Cave Spring may have resulted from successful forage management programs in the basin. Livestock population increased along with an increase in forage production during the course of study. Increased forage production resulted mainly from management changes that did not include increased inorganic nutrient additions.

A significant decreasing trend in nitrate-N concentrations at Davis Spring may have been a result of increased urbanization and commercial development in Lewisburg. As farmland decreases and paved areas increase, less water infiltrates through the soil, where nitrification of N contributes nitrate.

Water appearing at the springs is an integrator of all impacts within the basins. Voluntary programs might not be reaching some of the "worst offender" sites within the basins, thus inadvertently sabotaging attempts at water quality improvement at the watershed scale. In order for water quality improvement programs to have sustainable positive impacts at the watershed scale, it might be necessary to target specific sites rather than relying solely on voluntary cost-sharing efforts. A careful analysis of the balance between agricultural production goals, water quality goals, and inherent environmental sensitivity is necessary to maintain an economically viable agribusiness while protecting water quality in karst areas.

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